In situ electrostatic separation of ambient $PM_{2.5}$ into source-specific fractions during collection in a FRM sampler

Final Report
University Coal Research: Innovative Concepts – Phase I

Reporting Period Start Date: 8/1/2005
Reporting Period End Date: 7/31/2006

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Date Report was Issued: October 2006

DOE Award Number: DE-FG26-05NT42543

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ABSTRACT

Coal combustion is generally viewed as a major source of $PM_{2.5}$ emissions into the atmosphere. For some time, toxicologists have been asking for an exposure environment enriched with the coal combustion source specific $PM_{2.5}$ to conduct meaningful exposure studies to better understand the mechanisms of the adverse health effects of coal combustion specific $PM_{2.5}$ in the ambient environment. There are several unique characteristics of primary PM generated from coal combustion. In this research project, an attempt has been made to exploit some of the unique properties of PM generated from coal fired power plants to preferentially separate them out from the rest of the primary and secondary PM in the ambient environment. An existing FRM sampler used for monitoring amount of $PM_{2.5}$ in the ambient air is modified to incorporate an electrostatic field. A DC corona charging device is also installed at the ambient air inlet to impart positive or negative charge to the PM. Visual Basic software has been written to simulate the lateral movement of PM as it passes through the electrostatic separator under varying operating conditions. The PM samples collected on polycarbonate filters under varying operating conditions were extensively observed for clustering and/or separation of PM in the direction parallel to the electric field. No systematic PM separation was observed under any of the operating conditions. A solution to overcome this kind of turbulence caused remixing has been offered. However, due to major programmatic changes in the DOE UCR program, there are no venues available to further pursue this research.

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Executive Summary

Toxicological studies have shown strong associations between elevated levels of airborne particulate matter (PM) instilled in the trachea of animals and adverse health effects. Coal combustion is generally viewed as a major source of $PM_{2.5}$ emissions into the atmosphere. For some time, toxicologists have been asking for an exposure environment enriched with the ambient as well as source specific $PM_{2.5}$ to conduct meaningful exposure studies to better understand the mechanisms of the adverse health effects of $PM_{2.5}$ and to further separate and identify specific adverse health effects of $PM_{2.5}$ from those of the other harmful gaseous components (e.g. CO, NO_x, and SO_x)

There are several unique characteristics of primary PM generated from coal combustion. During coal combustion at high temperatures, all organic and volatile components are oxidized to gaseous phases. Remaining predominantly aluminosilicates are fluxed with alkali, alkaline earth and iron compounds to form glassy molten phases. When cooled from high combustion temperatures to ambient temperature, these molten phases retain their spherical morphology. This spherical morphology decreases the specific surface area of PM, which in combination with the removal of volatile active species during high temperature exposure and formation of glassy phases makes such PM chemically inert. Moreover, spherically shaped particles can easily move in and out of human airways instead of getting embedded in the lung alveoli. Glassy phases in PM from coal combustion are usually electrical insulator are amenable to electrostatic separation.

In this research project, an attempt has been made to exploit some of the unique properties of PM generated from coal fired power plants to preferentially separate them out from the rest of the primary and secondary PM in the ambient environment. An existing FRM sampler used for monitoring amount of $PM_{2.5}$ in the ambient air is modified to incorporate an electrostatic field. The ambient air path through the sampler is modified to pass through this electrostatic separator with floating plate DC voltages in the range of 0-10kV. A DC corona charging device is also installed at the ambient air inlet to impart positive or negative charge to the PM. A Visual Basic software has been written to simulate the lateral movement of PM as it passes through the electrostatic separator under varying operating conditions.

To rapidly collect samples at different electrostatic voltage potentials, with and without +/- 10 kV corona pre-charging, ambient air inlet was spiked with resuspended coal fly ash collected from utility plant boiler ESP unit. The PM samples collected on polycarbonate filters under varying operating conditions were extensively observed for clustering and/or separation of PM in the direction parallel to the electric field.

No systematic PM separation was observed under any of the operating conditions. Further little modifications in improving flow paths were also unsuccessful.

Consultation with a commercial firm dealing with triboelectric separation of material revealed that they had also encountered similar problems when the straightened flow entering the electrostatic separator was not matched with an auxiliary flow of clean air with the same linear

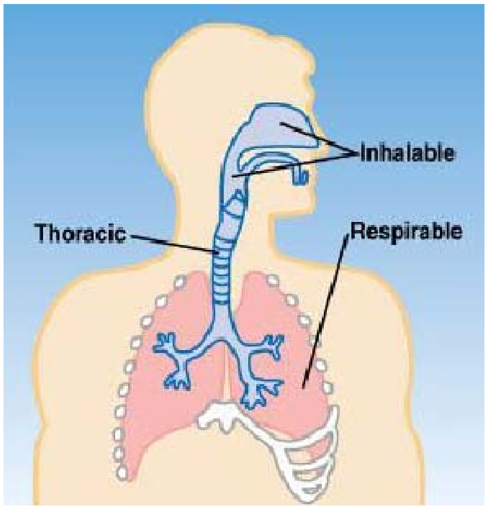
velocity. The turbulence set in at the inlet of the electrostatic separator is too large and the laminar flow is not fully restored prior to the PM stream leaving the separator.

A solution to overcome this kind of turbulence caused remixing has been offered and a separate proposal as Phase II of the program was prepared to collect larger, real time sample without using the FRM sampler has been formulated. Unfortunately, due to complete change in the format of the UCR program, not only are the Phase I/Phase II proposals eliminated but the subject of environmental research has also been removed. Hence, there are no future plans of continuation of this research.

In situ electrostatic separation of ambient $PM_{2.5}$ into source-specific fractions during collection in a FRM sampler

Introduction

In July 1997, the EPA promulgated stricter primary and secondary National Ambient Air Quality Standards (NAAQS) for ambient airborne particulate matter (PM) by including particles smaller than 2.5 µm in diameter ($PM_{2.5}$) that are inhalable and can be deposited in the lower (thoracic and respirable) regions of the human respiratory tract. EPA has placed approximately 1000 monitors across the country to measure ambient amounts of $PM_{2.5}$, one of the six criteria pollutants. To correlate the data from this many measurements sites and monitors, EPA has established a federal reference method (FRM) sampling instrument for $PM_{2.5}$ collection and gravimetric measurement procedures to determine the mass of samples collected using the FRM sampler.



Toxicological studies have shown strong associations between elevated levels of source specific $PM_{2.5}$ instilled in the trachea of animals and adverse health effects. However, due to low gravimetric loadings of $PM_{2.5}$ in the ambient atmosphere, it is difficult to conduct inhalation exposure studies and to quantify the adverse health endpoints in animal as well as human subjects. For some time, toxicologists have been asking for an exposure environment enriched with the ambient as well as source specific $PM_{2.5}$ to conduct meaningful exposure studies to better understand the mechanisms of the adverse health effects of $PM_{2.5}$ and to further separate and identify specific adverse health effects of $PM_{2.5}$ from those of the other harmful gaseous components (e.g. CO, NO_x, and SO_x). Coal combustion is generally viewed as a major source of $PM_{2.5}$ emissions into the atmosphere.[1] Moreover, detailed chemical analyses of PM from various sources indicate that the chemistry of coal combustion PM is very different from the chemistries of other PM.[2] The emission control technologies of coal fired utilities have significant interdependence in controlling various emissions. For example, technologies used to decrease NO_x and Hg emissions, usually increase PM emissions.

There are several unique characteristics of primary PM generated from coal combustion. During coal combustion at high temperatures, all organic and volatile components are oxidized to gaseous phases. Remaining predominantly aluminosilicates are fluxed with alkali, alkaline earth and iron compounds to form glassy molten phases. When cooled from high combustion temperatures to ambient temperature, these molten phases retain their spherical morphology. This spherical morphology decreases the specific surface area of PM, which in combination with the removal of volatile active species during high temperature exposure and formation of glassy phases make such PM chemically inert. Moreover, spherically shaped particles can easily move in and out of human airways instead of getting embedded in the lung alveoli. Glassy phases in

PM from coal combustion are usually electrical insulator are amenable to electrostatic separation.

Objectives and Approach

1. To design, construct and incorporate an electrostatic deflector downstream of the $PM_{2.5}$ WINS impactor so that the fly ash particles generated from coal combustion are preferentially separated from the rest of the ambient $PM_{2.5}$ particles.
2. To collect these two, physically separated, source specific, ambient $PM_{2.5}$ streams onto a single standard filter.
3. To analyze the filters by SEM to quantitatively estimate efficiency and source specificity of the separation.

Results and Discussion

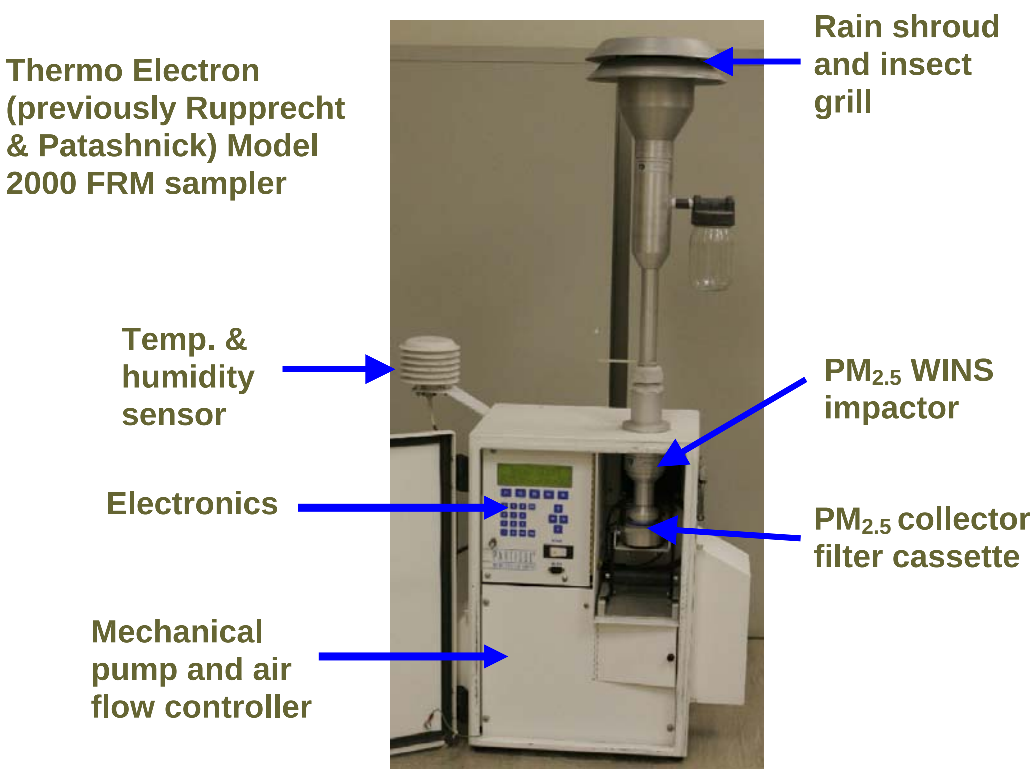


Figure 1. Photograph of an existing FRM sampler prior to modifications.

Figure 1 is a photograph of an existing FRM sampler located on the roof of the law building at the University of Kentucky. This sampler was calibrated and tested by collecting ambient $PM_{2.5}$ for 24 hour period using the standard PTFE filter.

Filter selection

As shown in the figure 2 (left), blank PTFE filters used for EPA mandated gravimetric measurements have woven/stretched fibrous supports, and they trap $PM_{2.5}$ as the ambient air moves through them.

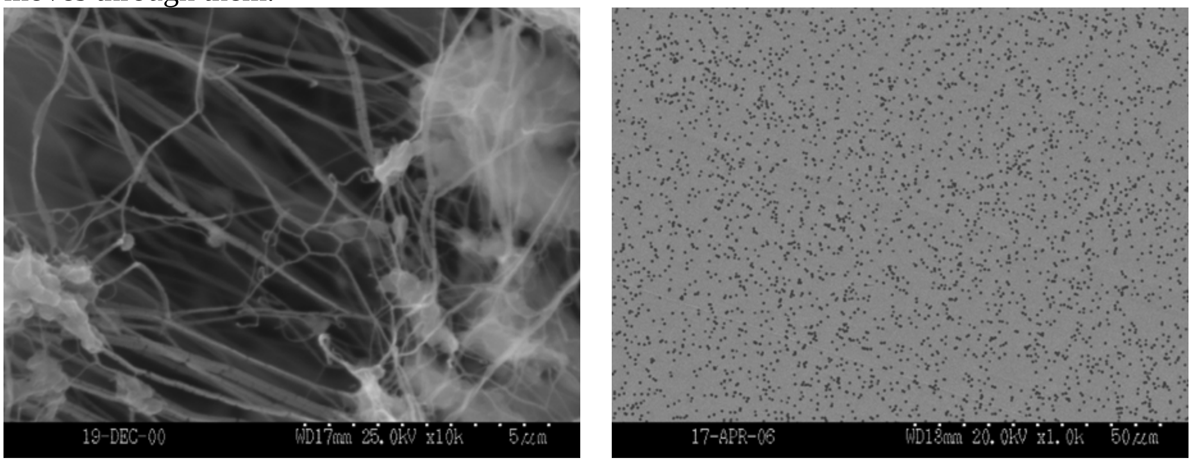


Figure 2. SEM images of (Left) a blank PTFE filter used for collecting ambient $PM_{2.5}$ in a FRM sampler, and (Right) 0.8 µm polycarbonate filter used for SEM analysis.

Because the captured particles are often located within the filter thickness and are obstructed by the fibrous structure, such filters are not ideally suited for SEM examination of collected $PM_{2.5}$. As a result, we acquired several batches of nucleopore polycarbonate filters with flat surface and varying size straight through pores. After testing different filters of pore sizes ranging from 0.08 microns to 8 microns, filters on 0.8 microns were selected for collecting all future $PM_{2.5}$. This was the smallest pore size which could sustain the required 1 m^3/hr (16.7 lit./m) flow rate for FRM sampler over 24 hour period.

Modification of sampler

As shown in figure 4 (left), FRM sampler has two different impactors for stripping $PM_{2.5}$+ size particles from ambient air before collecting $PM_{2.5}$ on a filter. Because of the geometrical constraints, there was no space left to install an electrostatic deflector in the flow path. As shown in the figure 4 (center), the sampler was modified by installing a very sharp cut cyclone (VSCC) downstream of the 1st stage PM_{10} impactor. This VSCC serves the same purpose as WINS impactor, i.e. removes $PM_{2.5}$+ particles from the ambient air coming out of the PM_{10} impactor. In turn, the WINS impactor was replaced by a straight bypass tube. This bypass tube provided enough space to house an electrostatic deflector. Figure 4 (right) also includes a photograph of the modified sampler showing inclusion of VSCC, electrostatic precipitator as well as corona discharge ionizer at the top of the sampler near the ambient air inlet.

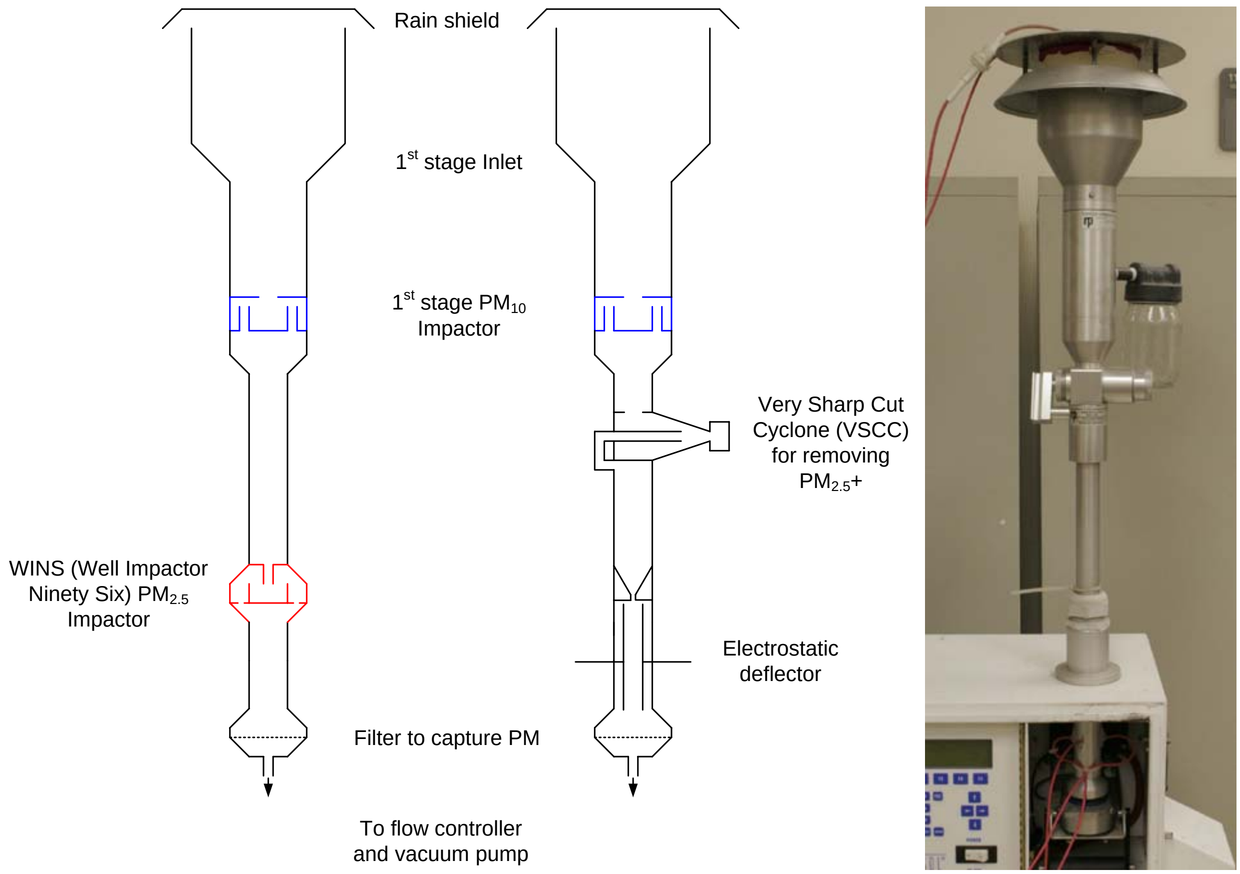


Figure 4. Schematics of an existing FRM sampler (left) and a sampler modified to incorporate electrostatic deflector (center). Photograph of the modified sampler (right)

Electrostatic deflector

Figure 5 shows detailed schematics of the electrostatic deflector design. The deflector is made up of two 3" long 5/8" wide aluminum plates separated by each other (5/8" apart) and the bypass tube by plexiglass spacers (figure 5, left). The deflector plates are independently powered by two variable unregulated 0-500V DC power supplies (model U450YA10, purchased from Acopian Power Supplies; http://www.acopian.com) with a common ground tied to the bypass tube and the rest of the sampler so that the plate voltages are floated with respect to ground.

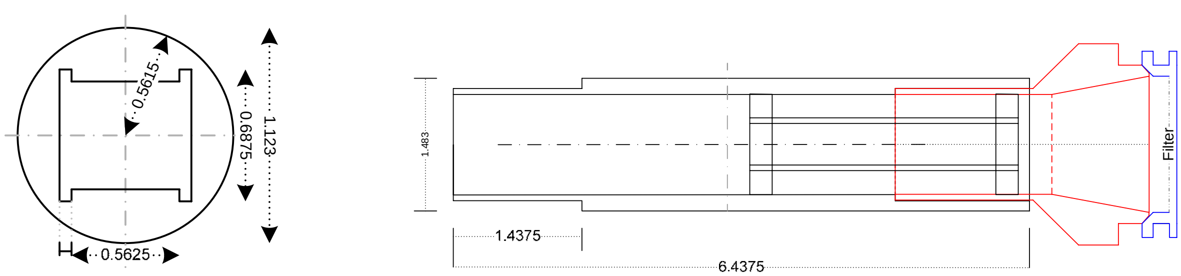


Figure 5. Schematics of a plexiglass insert to hold electrostatic deflector plates (left) and bypass tube, electrostatic deflector, and filter holder assembly (shown laid on its side) with the airflow going from left to right (right).

Corona discharge ionizer

To increase the efficiency of separation of electrically insulating ash particles from other particles in ambient air, a corona discharge ionizer Omnistat Model PNV10 ± 0-10 KV was purchased from Julie Static Controls (http://www.juliestaticcontrol.com/) and incorporate within the air inlet of the sampler such that the both positive and negative corona discharge covered the entire inlet of the 1st stage PM_{10} impactor. Figure 6 has two close up photographs of corona dischage ionizer (left) and electrostatic deflector (right) as installed in the sampler.

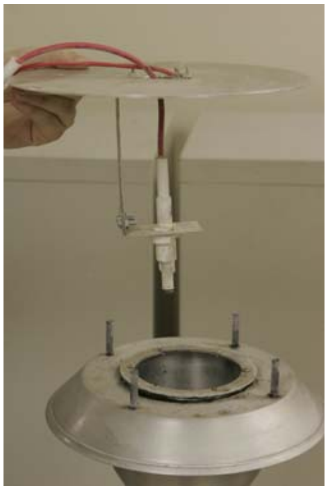


Figure 6. Photographs of corona discharge ionizer tip (left) and electrostatic deflector (right) as incorporated within the sampler.

Sample spiking

In the first few shakedown tests, it was noted that the ambient loading of the PM is quite low and no particles were collected within 30 minutes of sampling (0.5 m^3 of ambient air). Hence, it was decided to spike the ambient sample by dusting small amounts of very fine fly ash (from Cholla No.3 boiler's hot side ESP) close to the ambient air inlet. Figure 7 is a photograph showing the dusting procedure to spike the ambient sample.

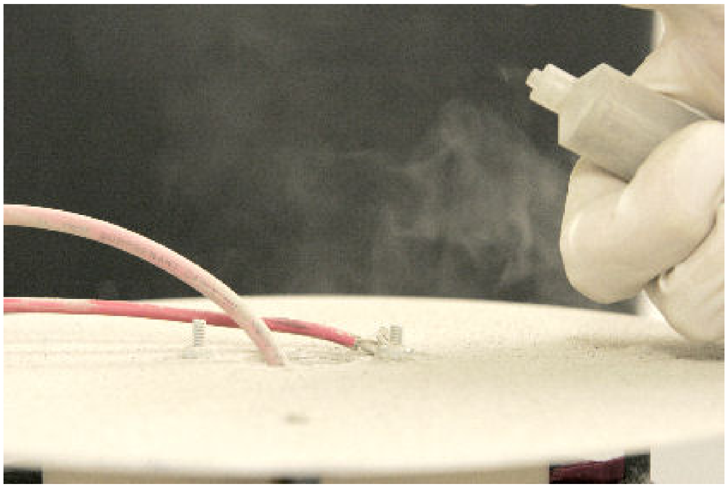


Figure 7. Dusting of very fine fly ash near the ambient air inlet for sample spiking.

Simulation software

A Visual Basic program was written to model the flow and predict deflection of $PM_{2.5}$ when passing through our design of electrostatic deflector. Figure 8 is a screen shot of this software.

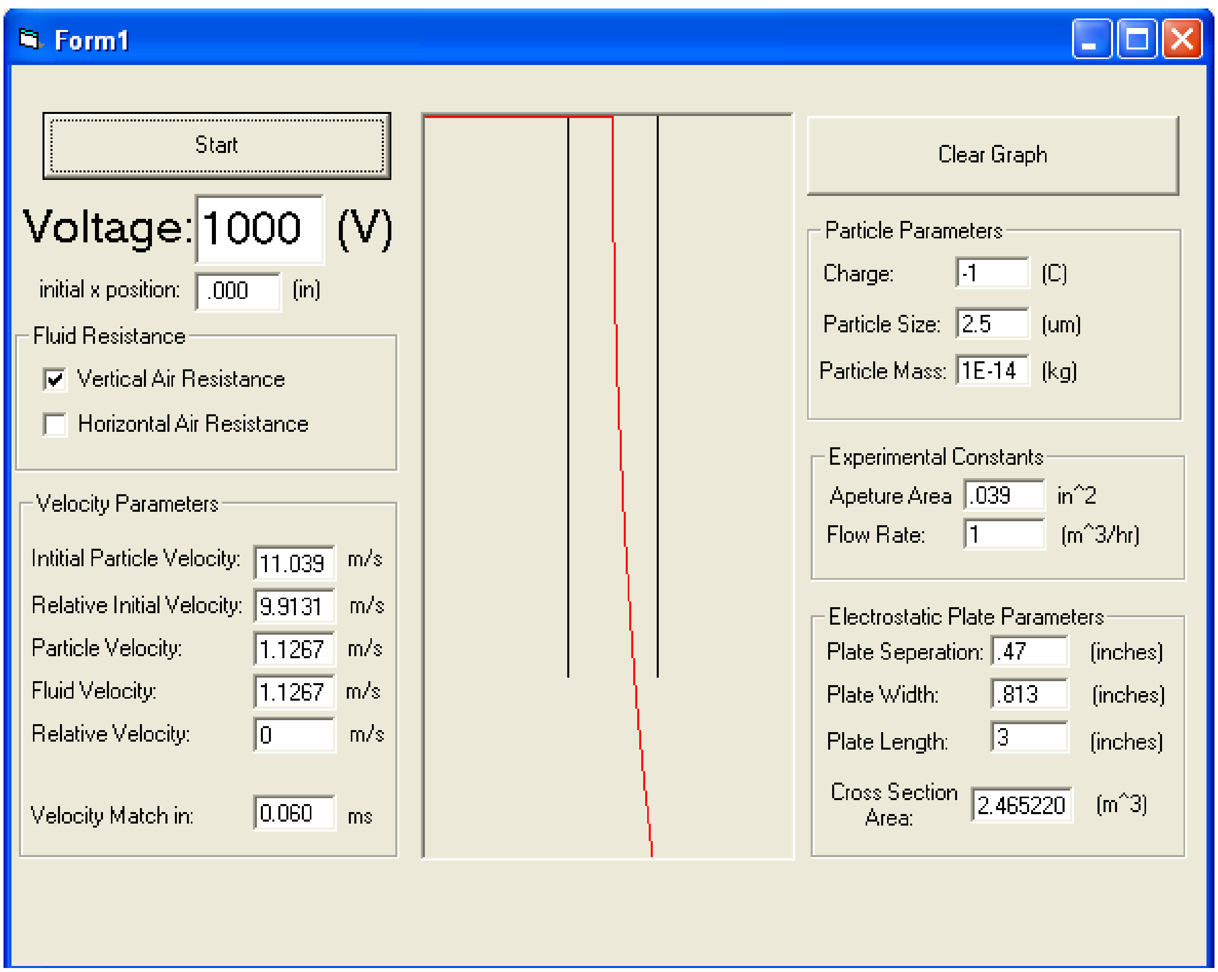
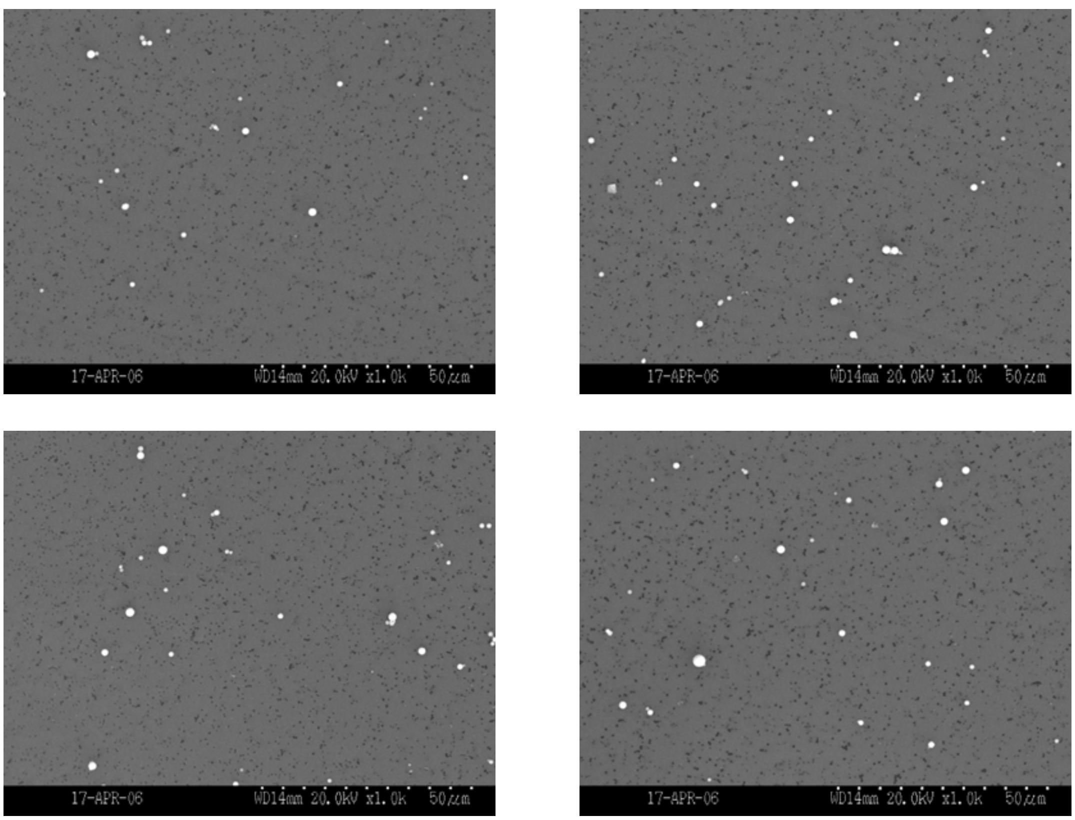


Figure 8. Screenshot of Visual Basic software written to model the trajectory of $PM_{2.5}$ as it passes through the electrostatic deflector in the modified FRM sampler.

Sample analysis

Several samples of artificially spiked samples were collected under different electrostatic deflector voltage settings and different corona discharge conditions on different polycarbonate filters. The 47 mm filters were cut into 10 mm side strips lengthwise perpendicular to the electrostatic plates and parallel to the electrostatic field. These strips were placed of aluminum strips wetted with colloidal graphite and plasma sputter coated with AuPd alloy to dissipate charge buildup in SEM. The strips were then examined using a back-scattered detector along their entire 47 mm length in 500 micron steps at 1000x magnification (field of view of about 100 microns) to find clustering and segregation of the particles. Figure 9 shows six typical SEM images along the length of one of the strips. Extensive SEM examination proved that the spiking of the sample was adequate to quickly collect samples and that there was NO significant clustering/segregation of particles under any of the electrostatic and corona discharge ionizer settings.



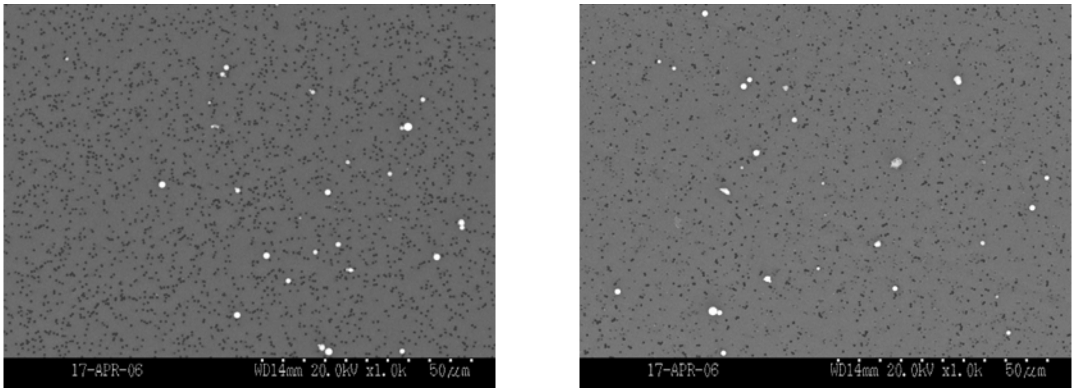


Figure 9. SEM micrographs of a polycarbonate filter strip along the electrostatic field on which Cholla No.3 fly ash spiked ambient PM were collected under 500 V electrostatic field and -10,000 V corona discharge potential

Further Modifications

Because there was no particle deflection/segregation observed under any of the voltage conditions, further modifications were made to the electrostatic deflector section. (Figure 10). A flow straightener was added upstream so that the ambient air flow is first choked to a narrow slit cross-section and then is forced to travel a short distance through the same slit dimensions to straighten out any lateral motions before being injected in the center of the electrostatic deflector. Previously, all the airflow and associated PM was being injected throughout the deflector cross-section and was exposed to varying potential. We also added several additional insulator disks throughout the straight section of the electrostatic deflector to reduce any flow around and behind the deflector plates. A flow separator plate was also added at the exit of the electrostatic deflector and touching the PM collection filter so that there is no lateral flow and remixing of the separated particle streams.

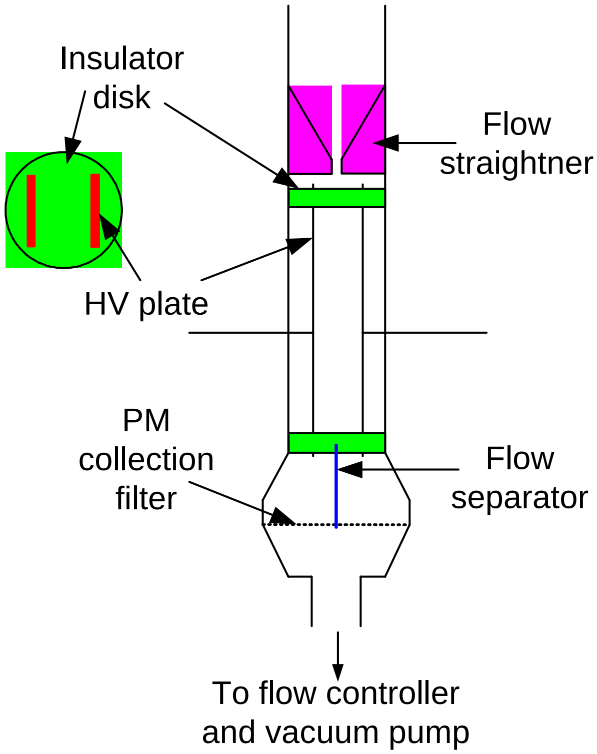


Figure 10. Schematic showing additional modifications made to the electrostatic deflector section of the sampler.

Sample Analysis

Several more spiked samples were collected under different voltage conditions and examined using SEM. However, the results were similar as before any modifications and no separation was observed.

At this point we consulted with Dr. John Stencel of TriboFlow Separations (http://www.tribiflow.com). TriboFlow has a patented process of separating particles in an air stream based on the differences in their electrical properties. Dr. Stencel confirmed our calculated potentials for our flow conditions for effective separation. However, he mentioned that when the air stream enters the electrostatic deflector after the flow straightener, there is sudden drop in linear velocity due to increase in cross-sectional area. This can cause formation of small eddies and some turbulence can set in with lateral motion of the stream. Because of this there is intermixing of the separated streams and separation cannot be achieved. As shown in figure 11, he suggested that we incorporate some kind of auxiliary flow to nullify this turbulence and increase separation efficiency.

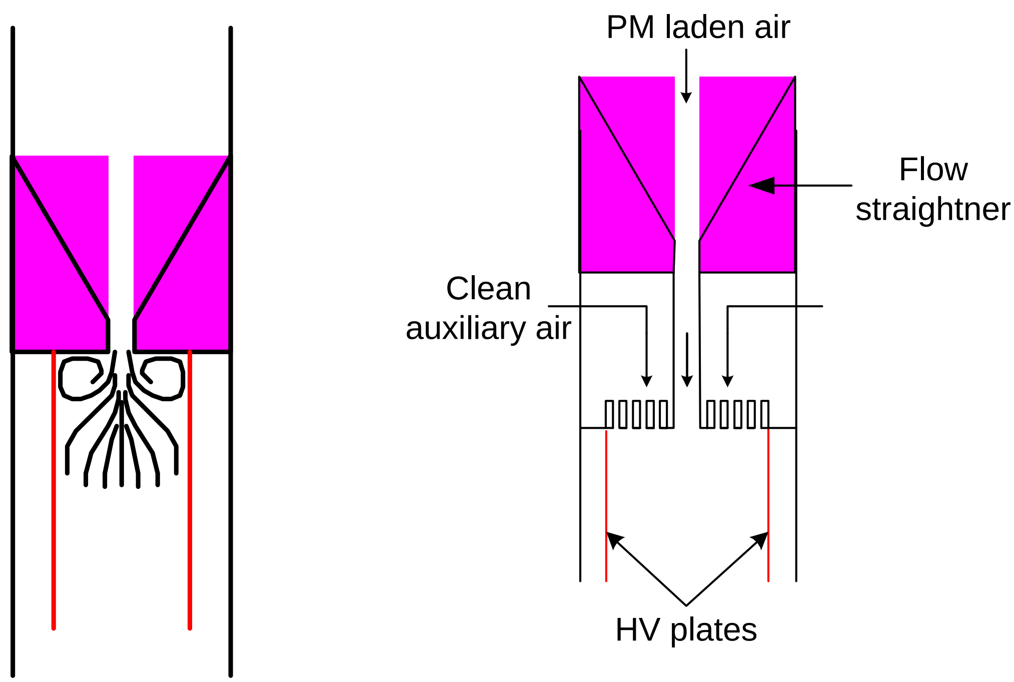


Figure 11. Schematics showing possible formation of turbulence (let) and an approach to reduce this effect (right).

Conclusions and Future Work

One year of funding for this project was obtained under innovative concepts phase 1 to demonstrate the proof of the concept. Clearly we have demonstrated the feasibility of incorporating an electrostatic deflector in an ambient FRM sampler. Based on the success of phase I, our goal was to seek for additional funding in phase II of the project to fully characterize the behavior of PM under electrostatic field and to deflect and extract a sub-stream of ambient air concentrated with PM, especially from coal combustion sources, so that it can be used for animal exposure studies.

Unfortunately, DOE has completely revamped the University Coal Research (UCR) program and not only done away with the Phase I/Phase II programs, but has eliminated the entire category of coal combustion emission research. Hence, currently we have no plans of any future work on this project.

Students Supported

Partial supports have been provided for the following students.
Nick Cprek
Mehul Suthar
Laal Seidu

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[2] Y. Zhang, X. Zhu, L. Zeng, W. Wang, " Source apportionment of Fine-Particle Pollution in Beijing" in Proceedings of Symposium "Urbanization, Energy, and Air Pollution in China: The Challenges Ahead", (2004)